MI-0202

Effects of the Longitudinal Variation in the Magnetic Field in the Recycler Combined Function Magnets

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Introduction

The prototype magnets constructed for the Recycler Ring have shown a variation in the vertical (B_y) field along the longitudinal axis of the magnets. This note describes an attempt to understand this effect on the lattice functions and the closed orbit.

The closed obit in the Recycler is most easily described if the beam enters and leaves the lattice magnets the same distance from the magnet center. I will denote this distance by x_i, the initial x coordinate of the beam as it enters the magnet. This will also be the value of the x coordinate as it leaves the magnet.

In addition I will look at the effect on the x_i, due to variations in the strength of the dipole field in the magnets.

If the Recycler Ring magnets were simply dipoles then the effect of the longitudinal variation, to a reasonable approximation, would be to reduce the average B_y field of the magnets, and hence the energy of the beam that would be stored in the Recycler. If the variation is parabolic along the axis of the magnet and at the end the fractional change in field is δ, the change in the momentum of the stored beam would be $dp/p = (-\delta)/3$.

The effect of the longitudinal variation is more complicated for the gradient magnets in the Recycler. It is possible to have the expected bend in a magnet, at the nominal momentum, by entering the magnet at other than the nominal entrance point and thereby changing the closed orbit within the magnet.

The gradient also makes it possible for magnets that have strengths which differ from the nominal strength to bend particles through the nominal bend angle provided they enter the magnet at the appropriate distance from the magnet center.

Because of the variation of the lattice functions along the Recycler magnets, the change in the focusing as the beam traverses the magnet means that the lattice functions and tunes will depend on the size of the variation.

In this note I will assume that the longitudinal variation of the field can be described by a parabola. I will describe the percentage change in the field from the ends to the midpoint of the magnet by δ

Lattice Function and Tunes

The Recycler lattice RRv11 has been translated from MAD format into the format used with TEVLAT. [1] A comparison of the tunes and lattice functions calculated using MAD and TEVLAT shows that the programs give the same results. All the calculations on the lattice described here were done using TEVLAT.

In order to represent the variation in field the bend magnets in the Recycler lattice were divided into three equal parts in the lattice description. The bend field, gradient, and sextupole components of the field in the middle and end sections differ depending on the assumed dip in the field. If the dip is δ then the field in the center section is

$$(1 - \delta/27)/(1 - \delta/3)$$

and the field in the end sections is

$$(1 - 13 \cdot \delta/27)/(1 - \delta/3)$$

relative to the field assuming that there was no dip in the field.

The tunes and lattice functions were computed as a function of δ. [2]

[1] A. Russell, Private Communication

[2] The fractional part of the base tunes, i.e. the tunes with $\delta = 0.0$ are $\nu_x = 0.427, \nu_y = 0.410$

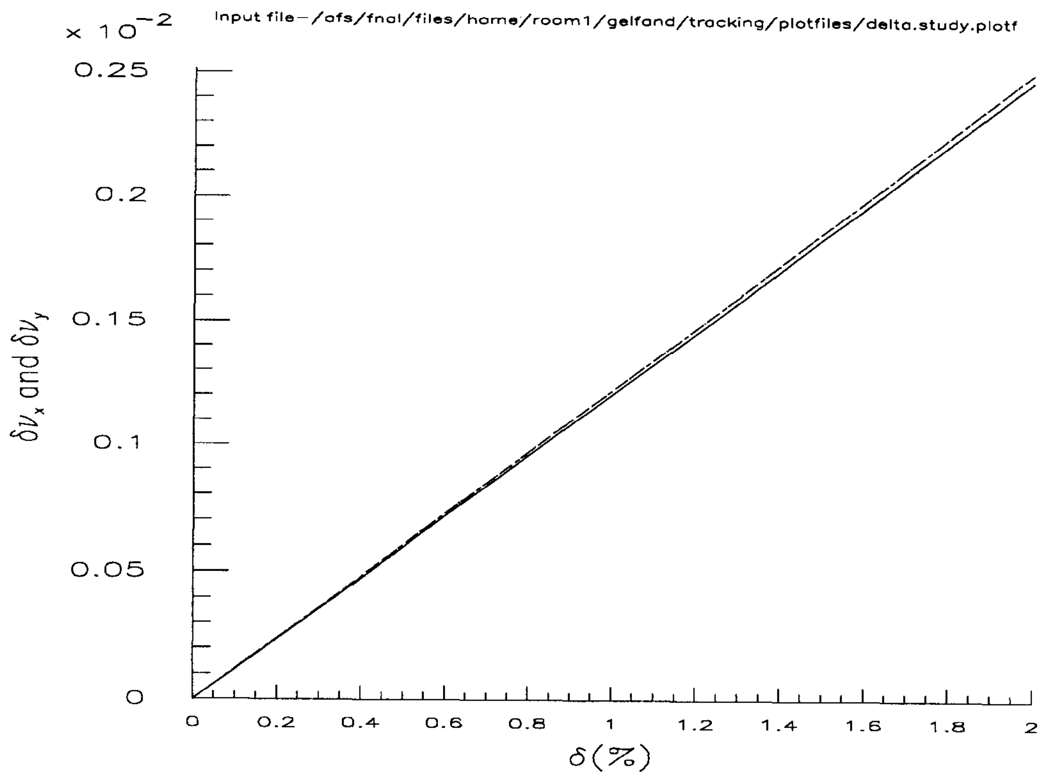

Figure 1: Change in Tunes as a Function of δ

The change in the tunes (figure 1) out to values of δ of 2% is linear.

Using the usual expression for the tune shift as a function of Δk_1 is,

$$\delta\nu = (1/4\pi) \cdot \sum \beta \cdot \Delta k_1 \cdot L$$

where

$\mathbf{\Delta k_1} = \Delta B'/[B\rho]$ and L is the length of the magnetic element.

Applying this formula with $\delta = 1\% = 10^{-2}$ I calculate

$$\delta\nu_x = 0.00116 \qquad \delta\nu_x = 0.00118.$$

These numbers should be compared with the TEVLAT results

$$\delta\nu_x = 0.00121 \qquad \delta\nu_x = 0.00123.$$

The agreement is very good.

The tune shift is no longer linear in δ for large values of δ. Figure 2 shows the tune shift out a value of $\delta = 20\%$.

The effect of the dip on the lattice functions can be estimated by looking at the change in β as a function of δ at a fixed location in the lattice. Figure 3 shows only a small change in the lattice functions over the range of δ out to 2%.

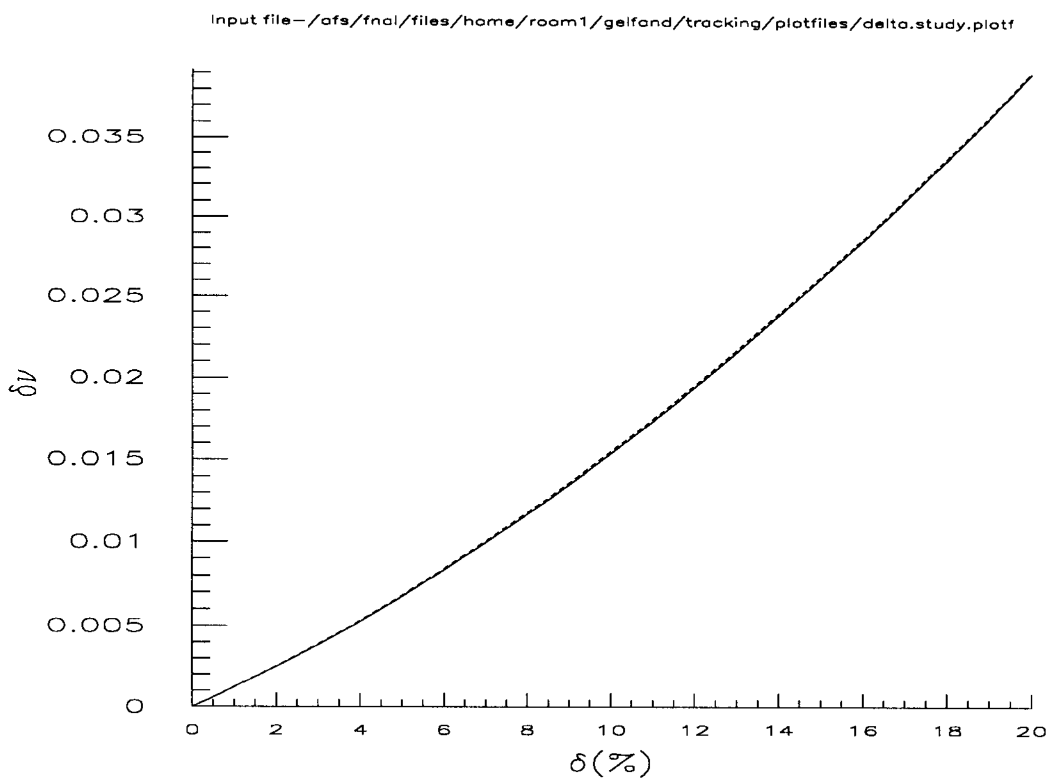

Figure 2: Change in Tunes as a Function of δ

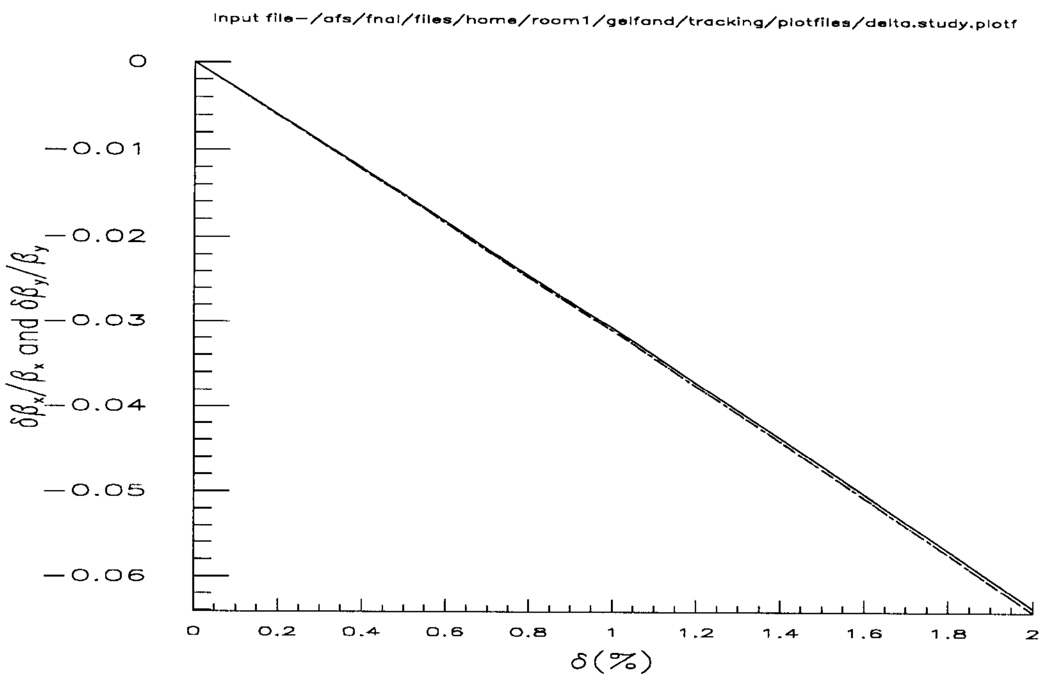

Figure 3: $\delta\beta/\beta$ as a Function of δ

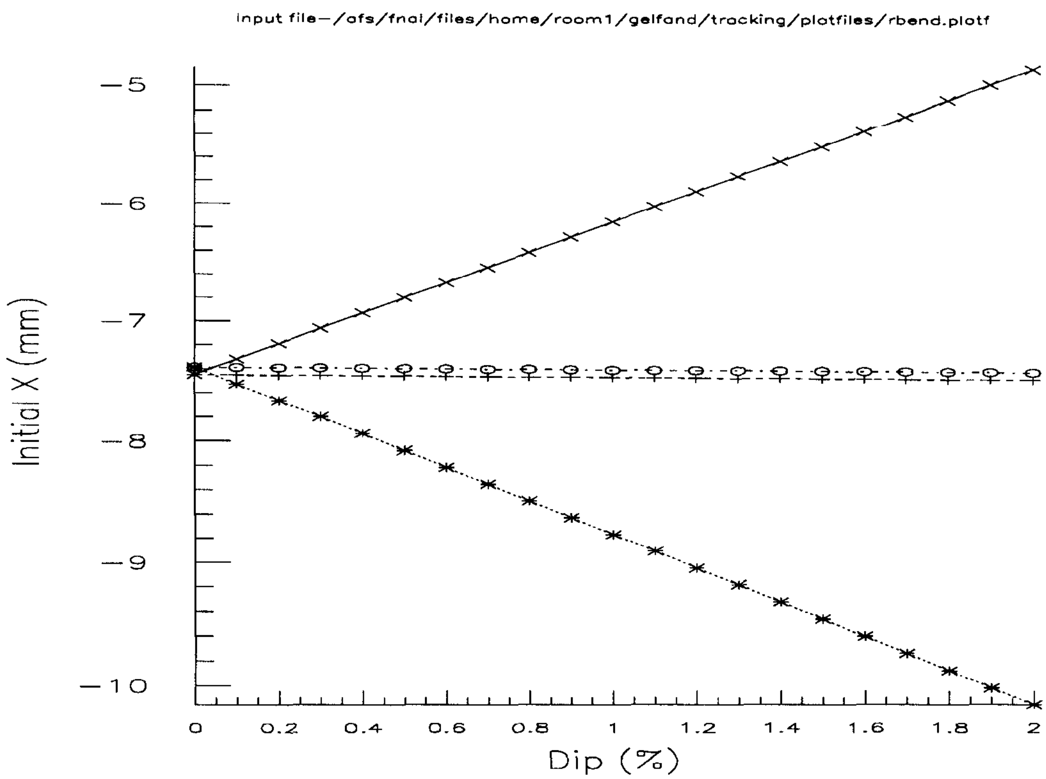

Figure 4: Change in the Initial Position of the Closed Orbit as a Function of $\delta(\%)$.

Closed Orbit

With the definitions and methodology described in MI-0200, the entry point of a particle, x_i, has been calculated for different values of δ *assuming* that the field strength at the center of the magnet is not adjusted for the longitudinal variation of B_y, (figure 4).

The entry point of the x_i depends on the longitudinal variation of B_y and on the gradient in the magnet, it being different for focusing and defocusing magnets. On the other hand if the central value of the field is adjusted so that the integrated field along the magnet center line is the nominal value, i.e. the value with no longitudinal variation, then the change in the entry

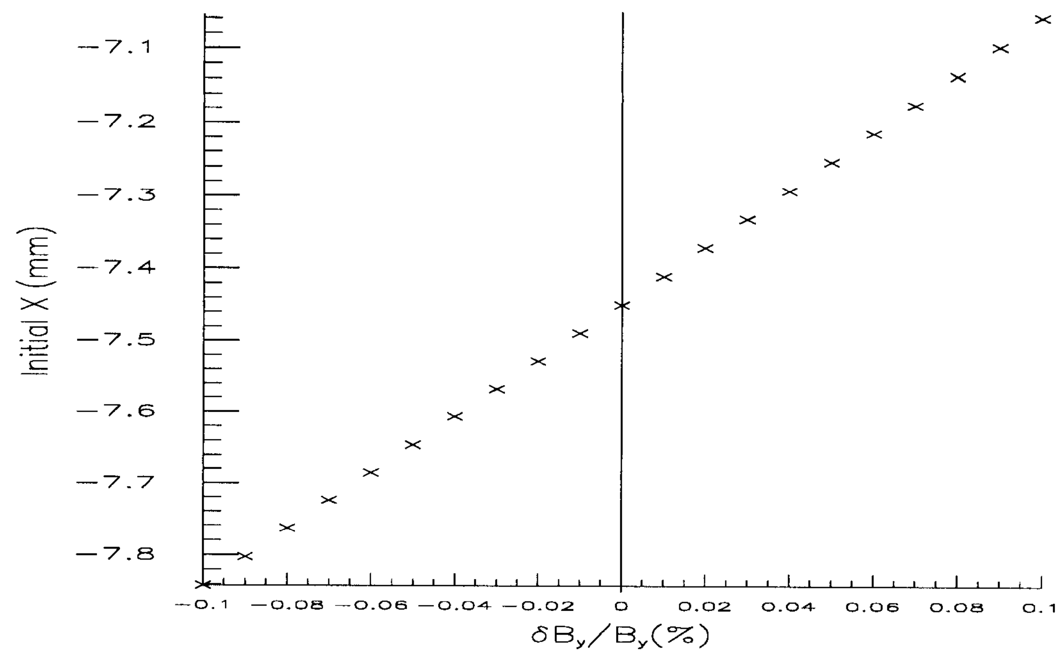

Figure 5: Change in the Initial Position of the Closed Orbit as a Function of $\delta B_y/B_y$.

point is small and independent of δ, (figure 4).

Thus, insofar as we are concerned with the value of x_i , if the $\int B_y \cdot dl$ along the center line of the magnet is maintained at its nominal value, despite the longitudinal variation, then this variation will have little effect on the x_i.

As an aside I note that it is possible to compensate for the variation in the strength of magnets by varying the entrance location of the beam. The change in the entrance location can be computed as a function of $\delta B_y/B_y$, (figure 5). The variation of the entrance location δx_i is $\approx 4mm/(\delta B_y/B_y)(\%)$. Thus, if the tolerances on the integrated field strength of

$$\delta B_y/B_y < 5 \cdot 10^{-4}$$

[redacted]